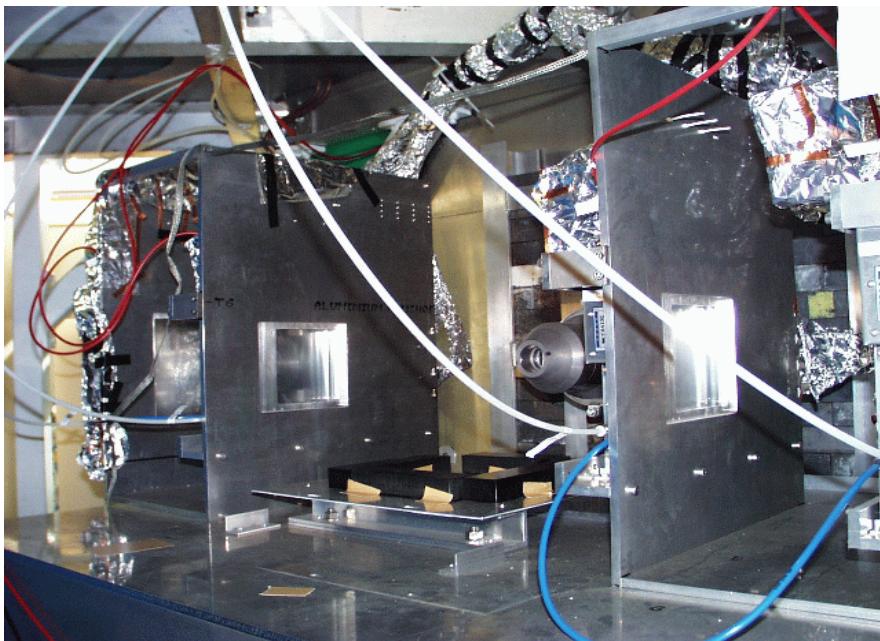


# Precision measurement of the positive muon lifetime at the RIKEN-RAL muon facility

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- Muon lifetime measurement and our experimental method
- Experimental setup
- Analysis
- Summary

# Muon Lifetime measurement

Associated with the Fermi Coupling constant

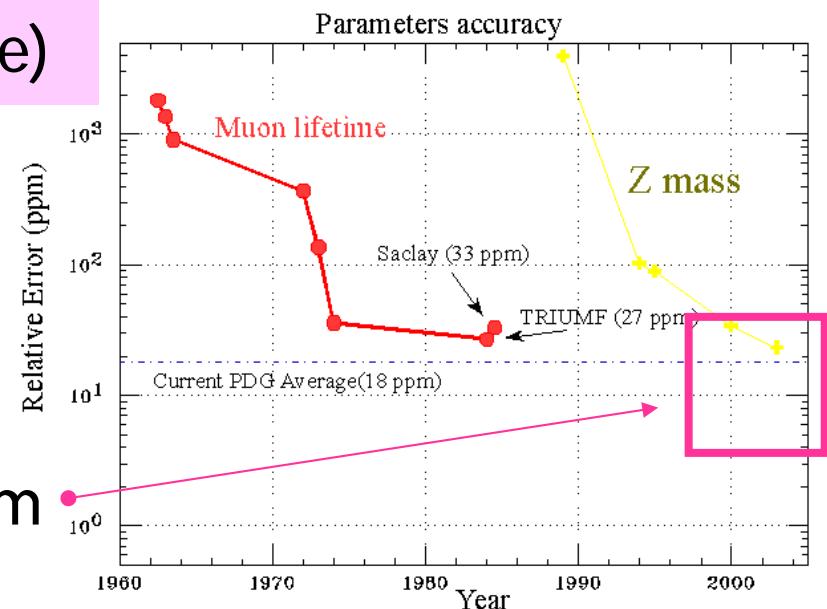
$$\tau_\mu^{-1} = \frac{G_F^2 m_\mu^5}{192\pi^3} F\left(\frac{m_e}{m_\mu}\right) \left(1 + \frac{3}{5} \frac{m_\mu^2}{M_W^2}\right) (1 + \Delta q)$$

GF : one of parameters in the electro-weak Standard Model

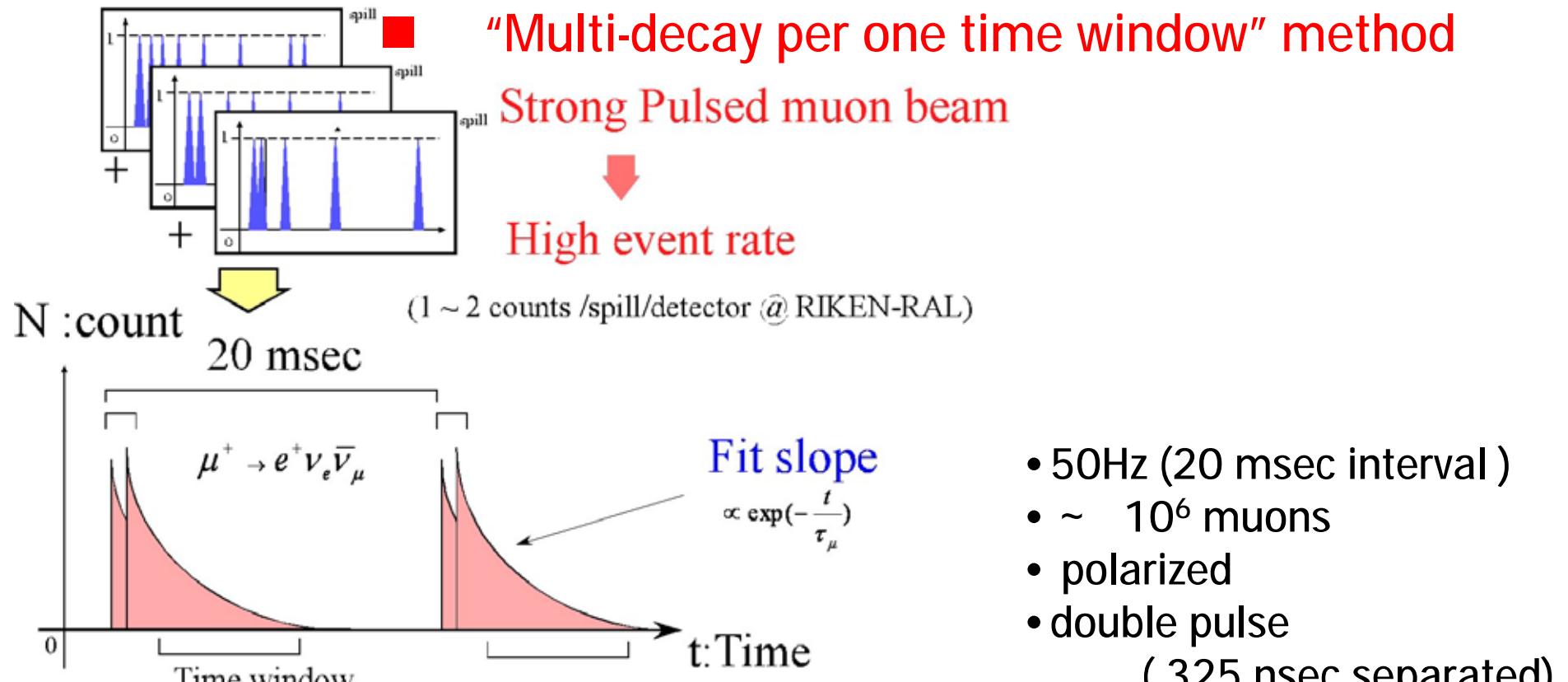
$$\alpha/\alpha \sim 0.045 \text{ ppm} \quad G_F/G_F \sim 9 \text{ ppm} \quad M_Z/M_Z \sim 22 \text{ ppm}$$



$$\tau/\tau \sim 18 \text{ ppm (PDG average)}$$



# Experiment at RIKEN-RAL



- 50Hz (20 msec interval)
- $\sim 10^6$  muons
- polarized
- double pulse (325 nsec separated)

■ Event rate  $> 10^4$  counts/sec

■ Less count-loss (largest systematic error)

- Highly segmented detector (MWPC)
- Develop an offline correction method (a few % of total events)

# Feature of Experimental setup

## I. Increase event rate, reduce and correct count-loss events

- Strong pulsed muon beam (50Hz,  $10^6$ /sec surface  $\mu^+$ )
- Highly segmented counters : MWPC (192 segments)
- Develop a method to correct count-loss events

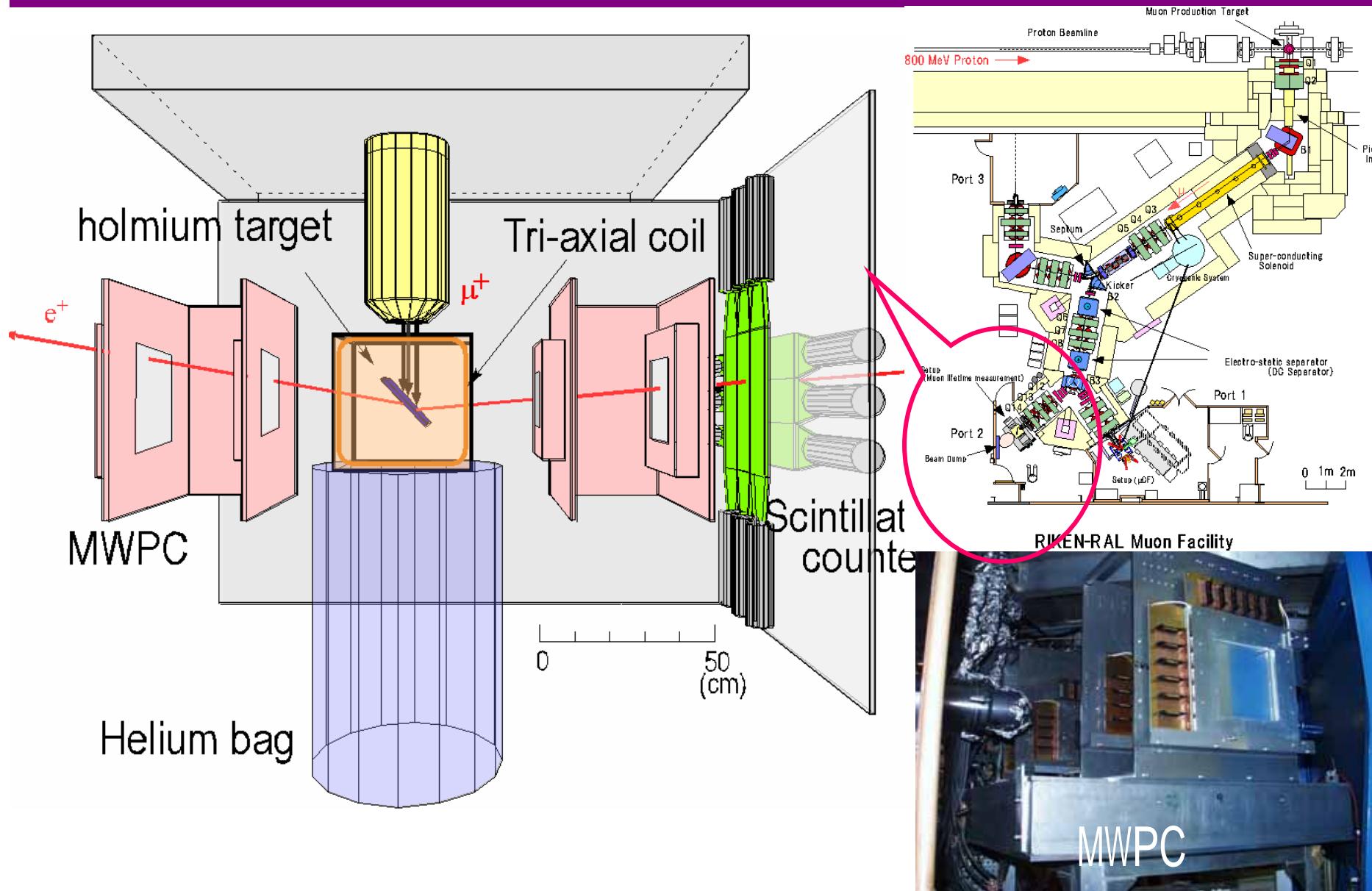
## II Selection of muon stopping target

- Reduce muon spin polarization effect
  - MWPC installed symmetrically
  - use paramagnetic Holmium metal ( $T_1 \sim 500$ nsec)

## III Accurate clock system and DAQ

- GPS signal synchronized with Latching Memory (LM)
- CAMAC multi-stop TDC and LM – 1280 ch (3 Mbyte/sec)

# Experimental setup at the RIKEN-RAL Port-II area

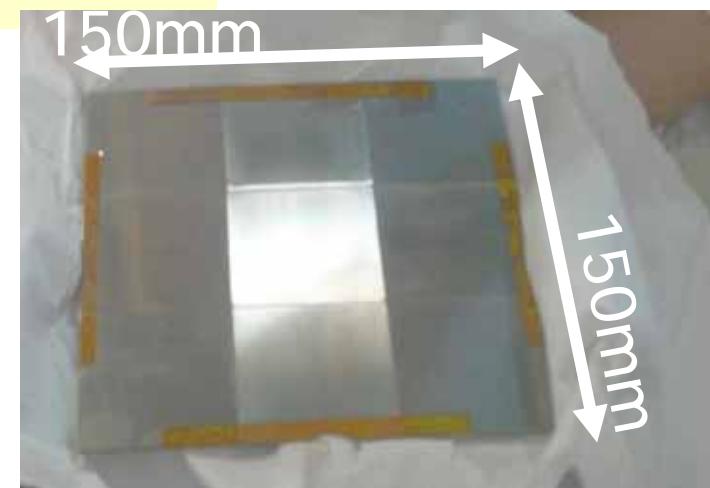
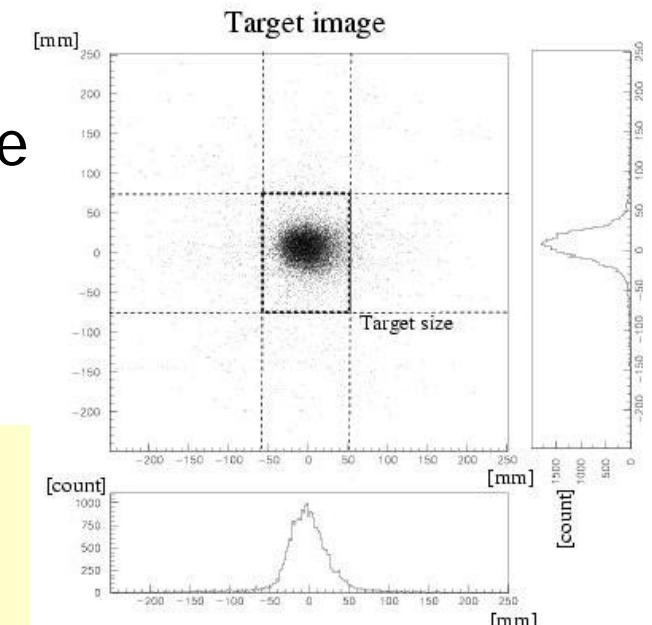
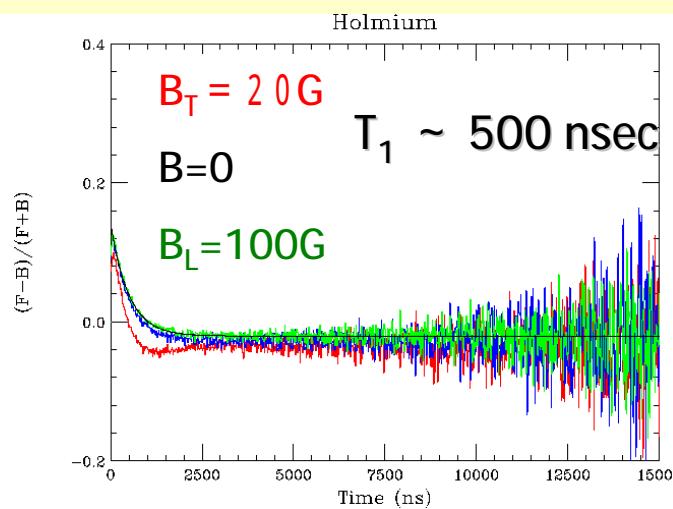


# Polarized muon spin effect

- anisotropic distribution of decay positron
- depolarize muon spin as rapidly as possible
- estimate residual spin asymmetry

➡ paramagnetic holmium in zero field

- Independent of external magnetic field
- Rapid and exponential relaxation ( $T_1 \sim 500$  nsec)
- relatively stable among rare earth metals



# Data Acquisition System & Clock System

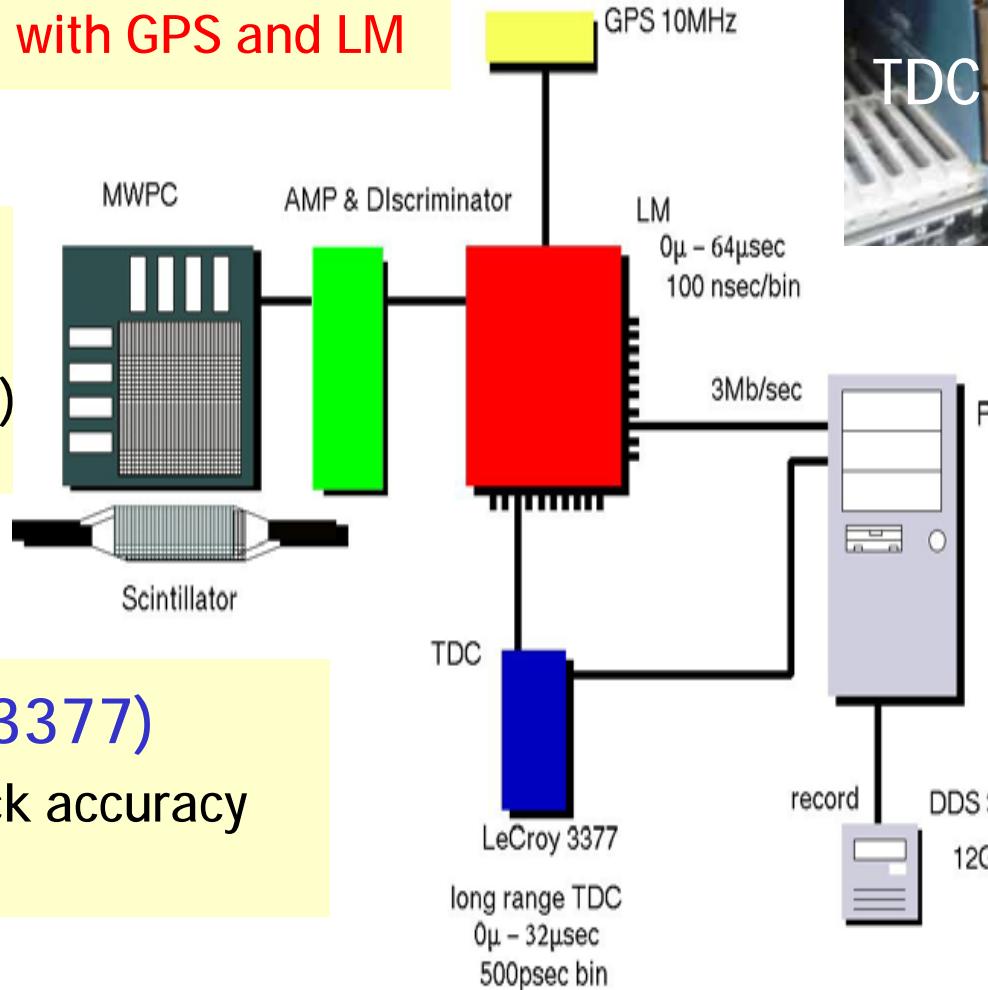
## ■ 4 CAMACs in parallel

### Accurate clock system

- GPS (10 MHz,  $\Delta t/t < 10^{-12}$ )
- synchronized with GPS and LM

### Latching Memory (LM)

- record at a GPS timing  
*(good linearity)*
- for time spectrum

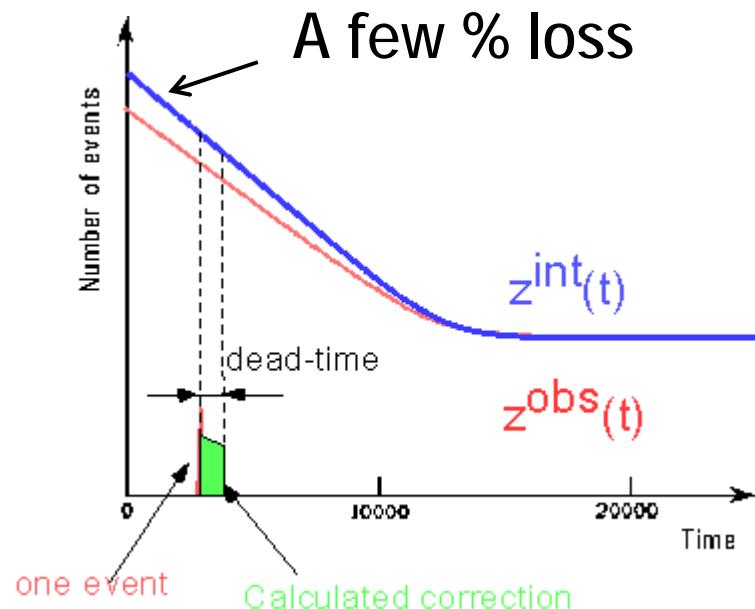


# Analysis - Count-loss Correction

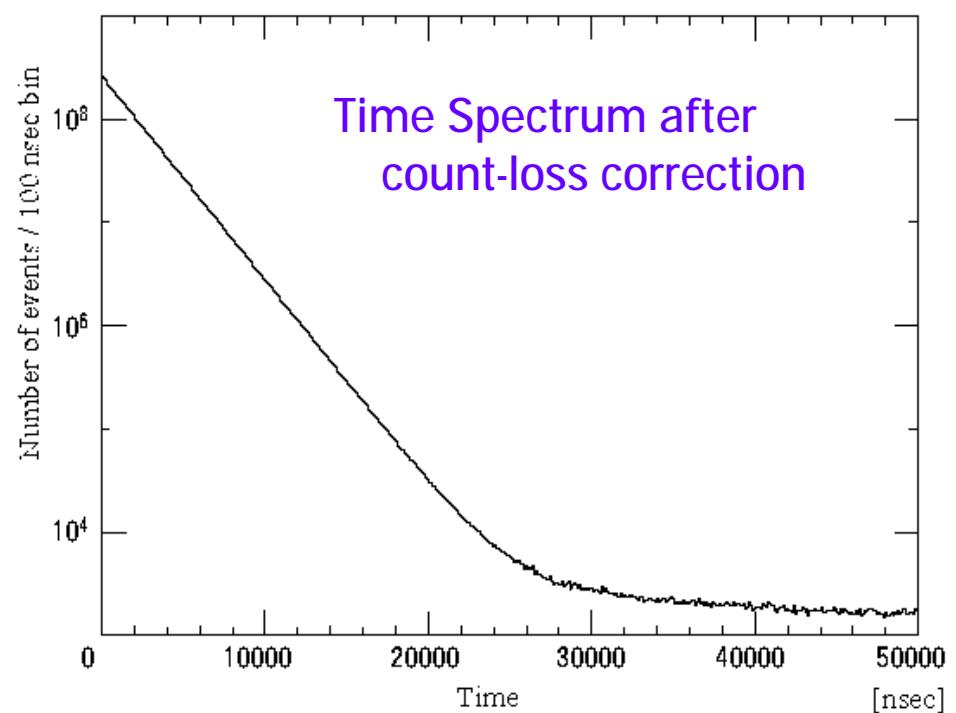
- numerical correction of count-loss events
- w/ count-loss ( $z^{obs}(t)$ ) and w/o coun-loss ( $z^{int}(t)$ ) spectra

$$z^{int}(t) = z^{obs}(t) + \int_0^{d_w} dt_d z^{obs}(t - t_d) c_{loss}(t_d, t - t_d)$$

- Event-by-event correction



Muon Decay Time Spectrum after Count-loss Correction

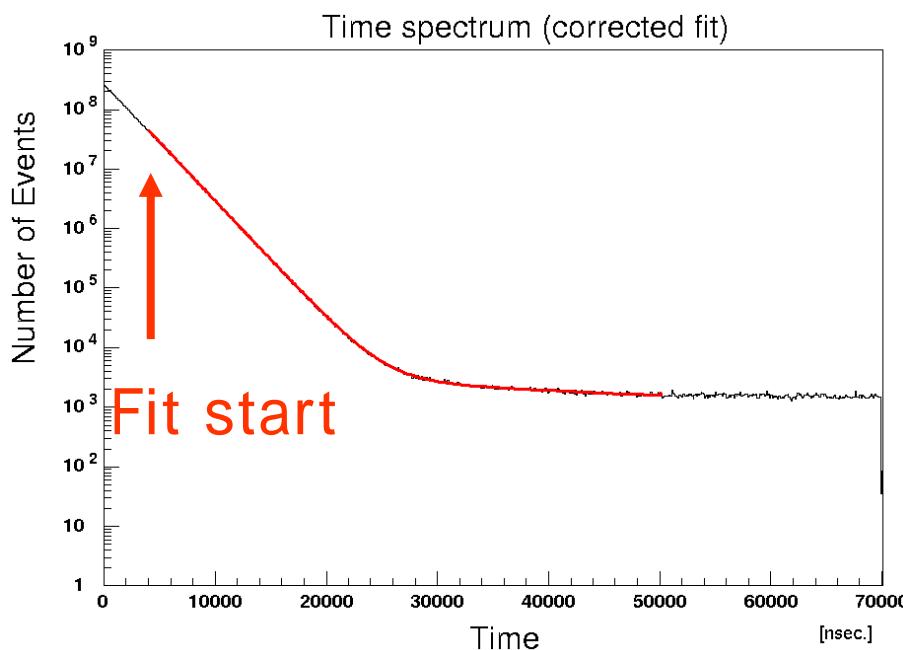


# Fit time spectrum

- Fit function and fit region

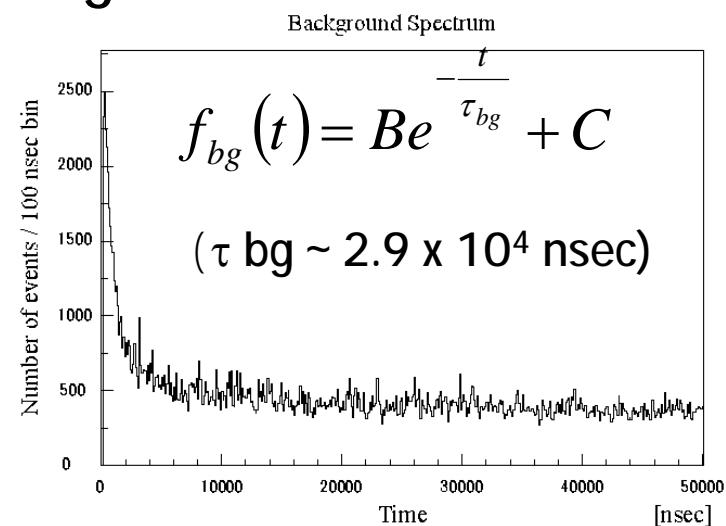
$$f(t) = A e^{-\frac{t}{\tau}} + B e^{-\frac{t}{\tau_{bg}}} + C$$

Decay positrons

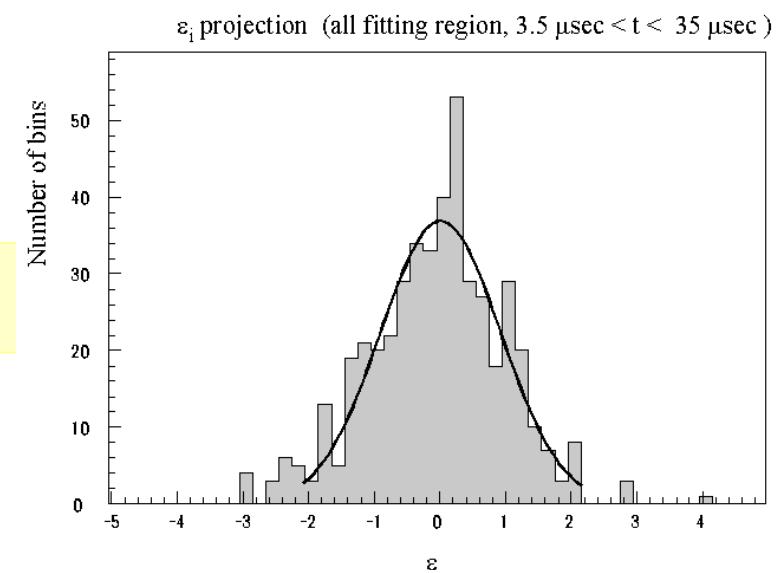
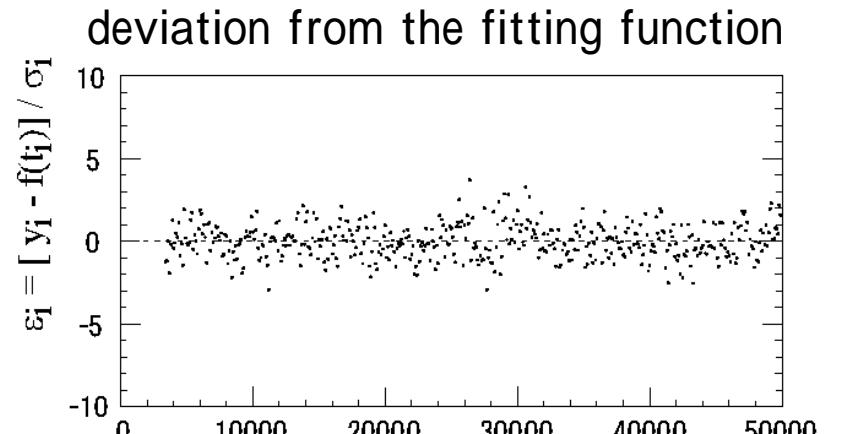
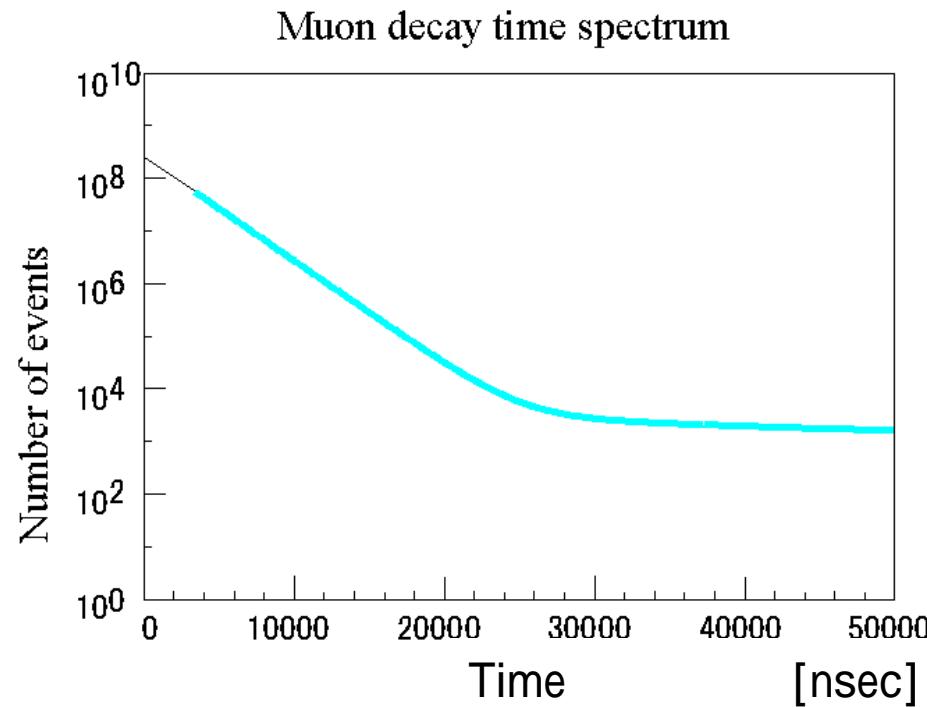


- 5 parameters fit

Background



# Preliminary Fit result



2004 analysis (Preliminary result)

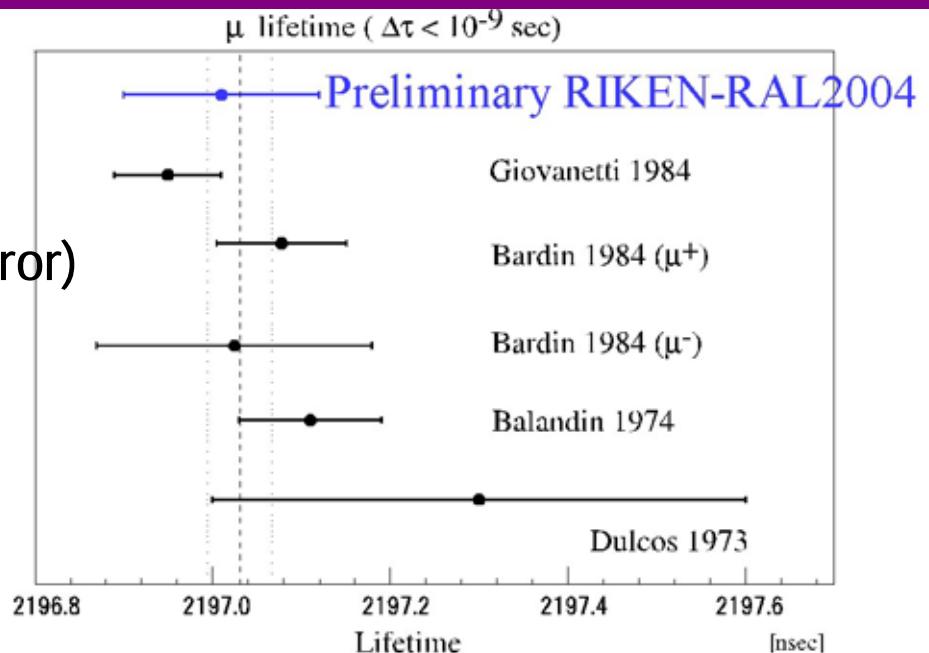
$$\tau_\mu = 2197.011 \pm 0.105 \quad (48 \text{ ppm}) \text{ [nsec]}$$

- statistical error
- fit start time  $t = 3500$  nsec

# Summary

## ■ Preliminary Result in 2004

$$\tau_\mu = 2197.011 \pm 0.105 \text{ (statistical error)}$$



## ■ Summary

- We obtained 2004 preliminary results : ~ 51 ppm (statistical + systematic )
- Estimate systematic error ( ~ 18 ppm , but not fixed yet )
- Now, re-analysis of all data set ( analysis efficiency improved )
- Fit start time should be adjusted ( $t=3500$  nsec -> possibly earlier )
- Available data set is expected to be larger than present data set
- Improve lifetime precision

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## Systematic error (around t = 0 msec )

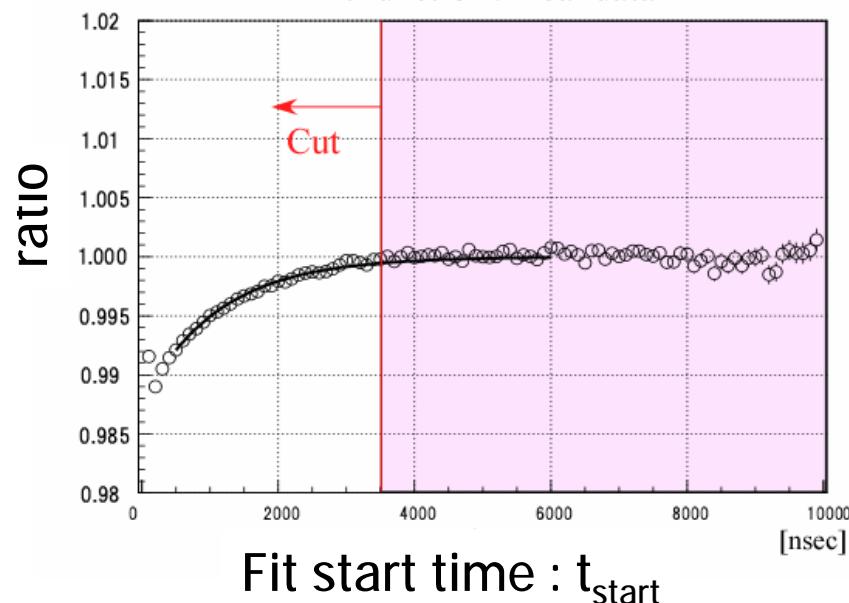
- minimize sum of systematic and statistical errors

- fit start time  $t_{\text{start}} = 3500 \text{ nsec}$  chosen

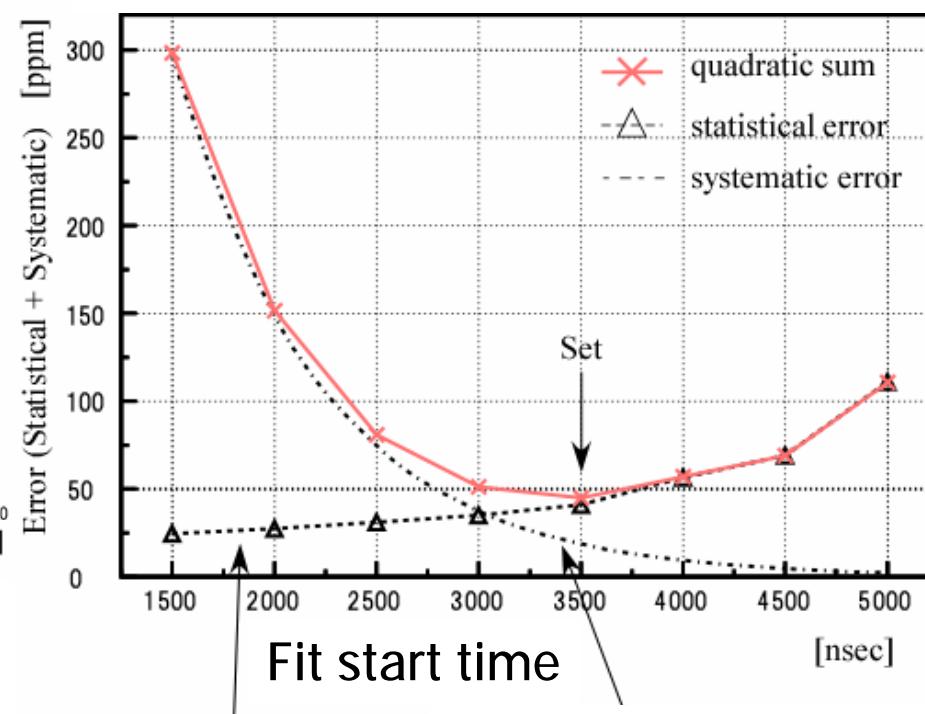


About 18 ppm

- data deviation from fit function  
( data /fit function )



- deviation from muon decay exponential function and statistical error



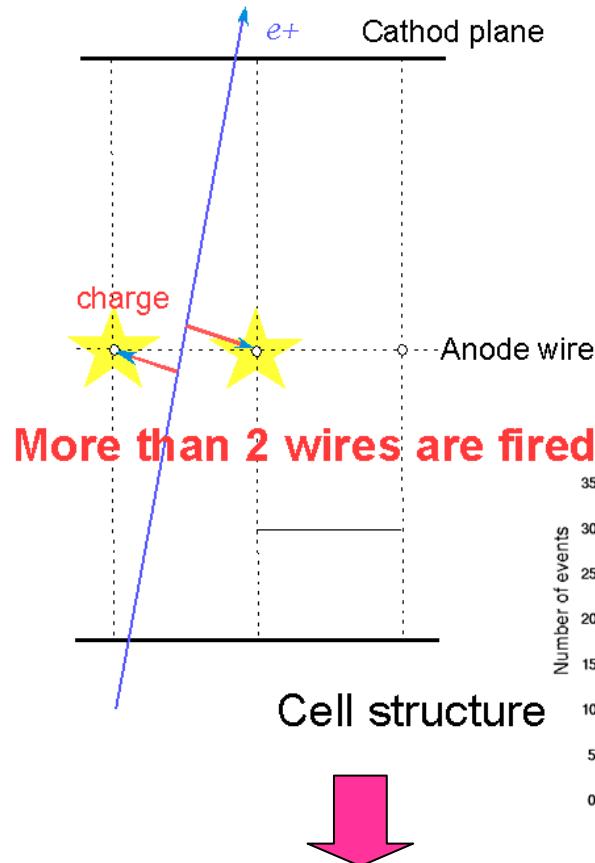
Statistical error

Deviation from exponential  
(translated into relative error )

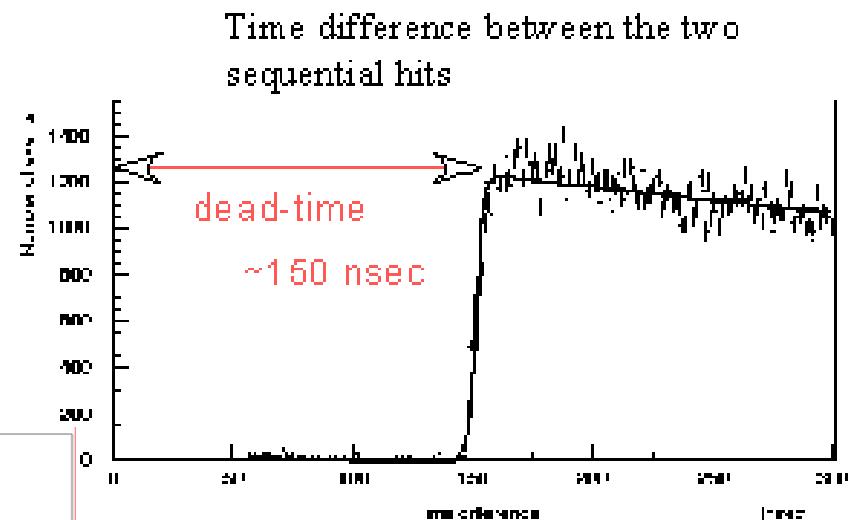
# TDC data analysis – MWPC wire information

- 1 nsec bin
- not very good linearity (internal clock accuracy)

## 1. estimate multi-wire hit effect



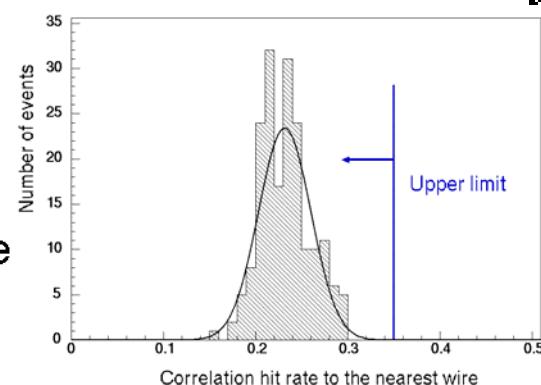
## 2. dead-time measurement



Average  $t_{\text{dead}} \sim 150$  nsec

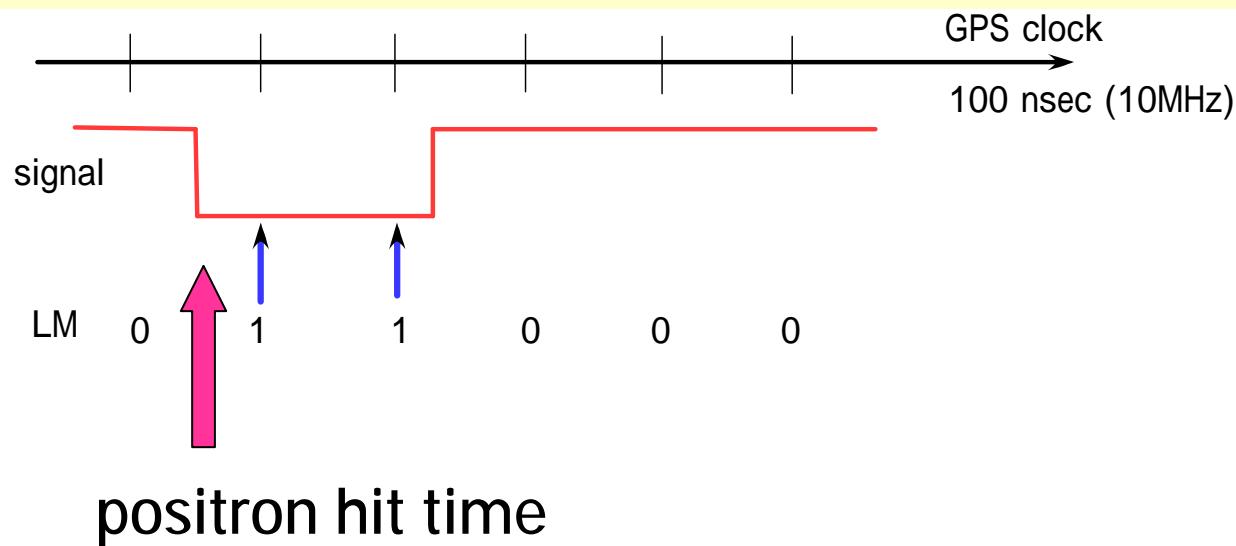
Measured for each wire

included a statistical error



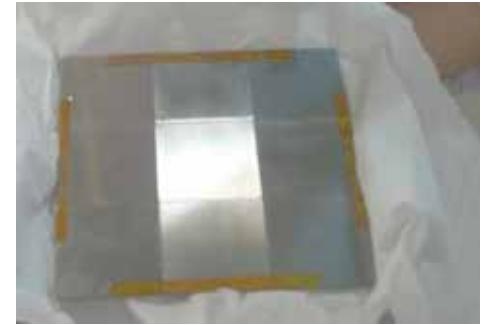
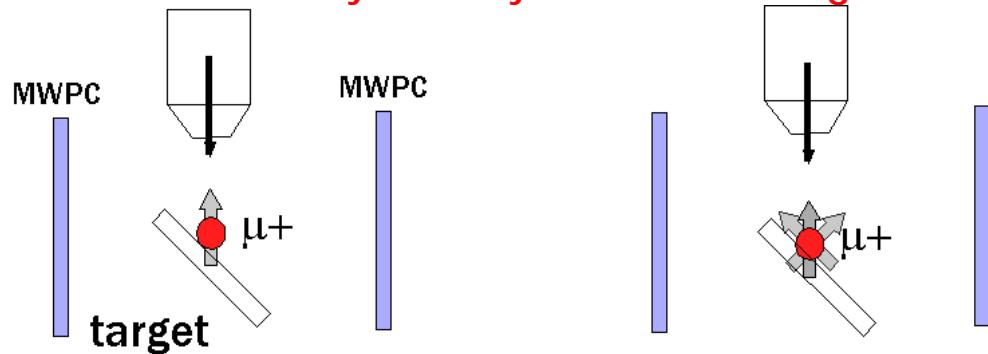
## LM data analysis – muon decay time spectrum

1. LM data → Time spectrum (remain count-loss)
2. Count-loss correction
3. Determine fitting region → fit result

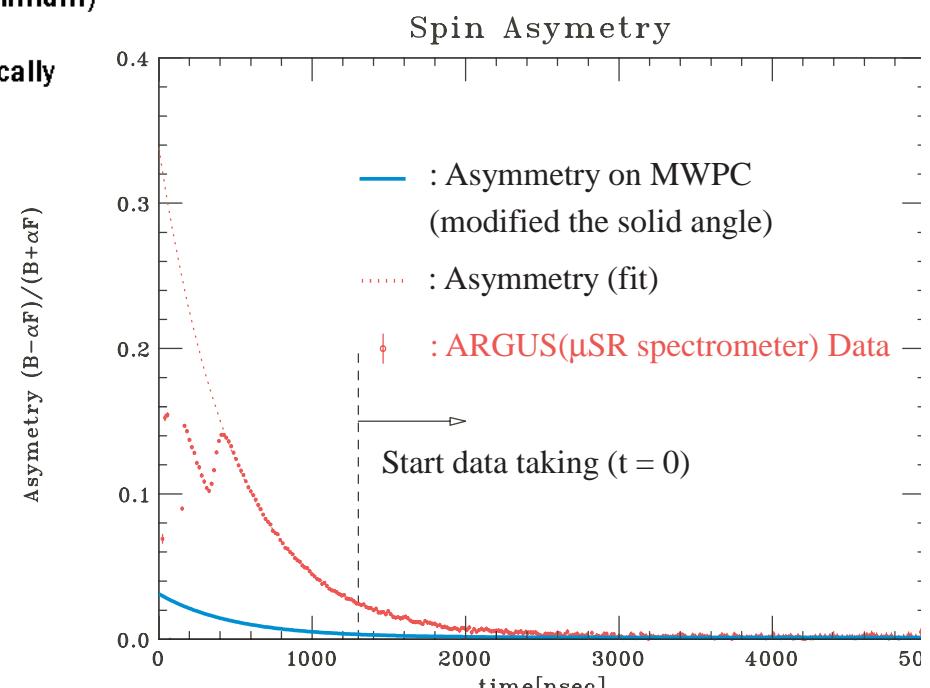
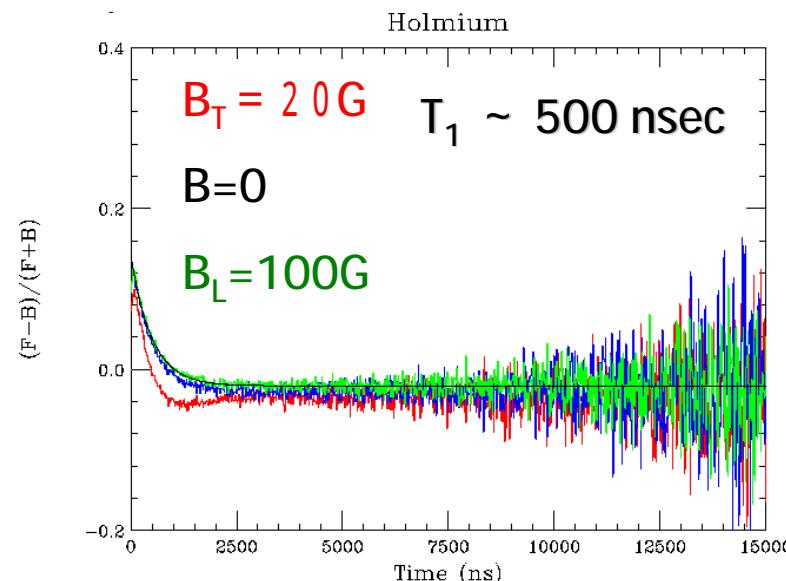


# Polarized muon spin effect

- To reduce asymmetry of electron angular distribution



- Polarized  $\mu^+$  stopped at the target
- $e^+$ : anisotropic distribution (preferably emitted to a muon spin direction)
- depolarized rapidly ( $T_1 : 500$  nsec for paramagnetic Holmium)
- After depolarization, decay  $e^+$  is emitted isotropically



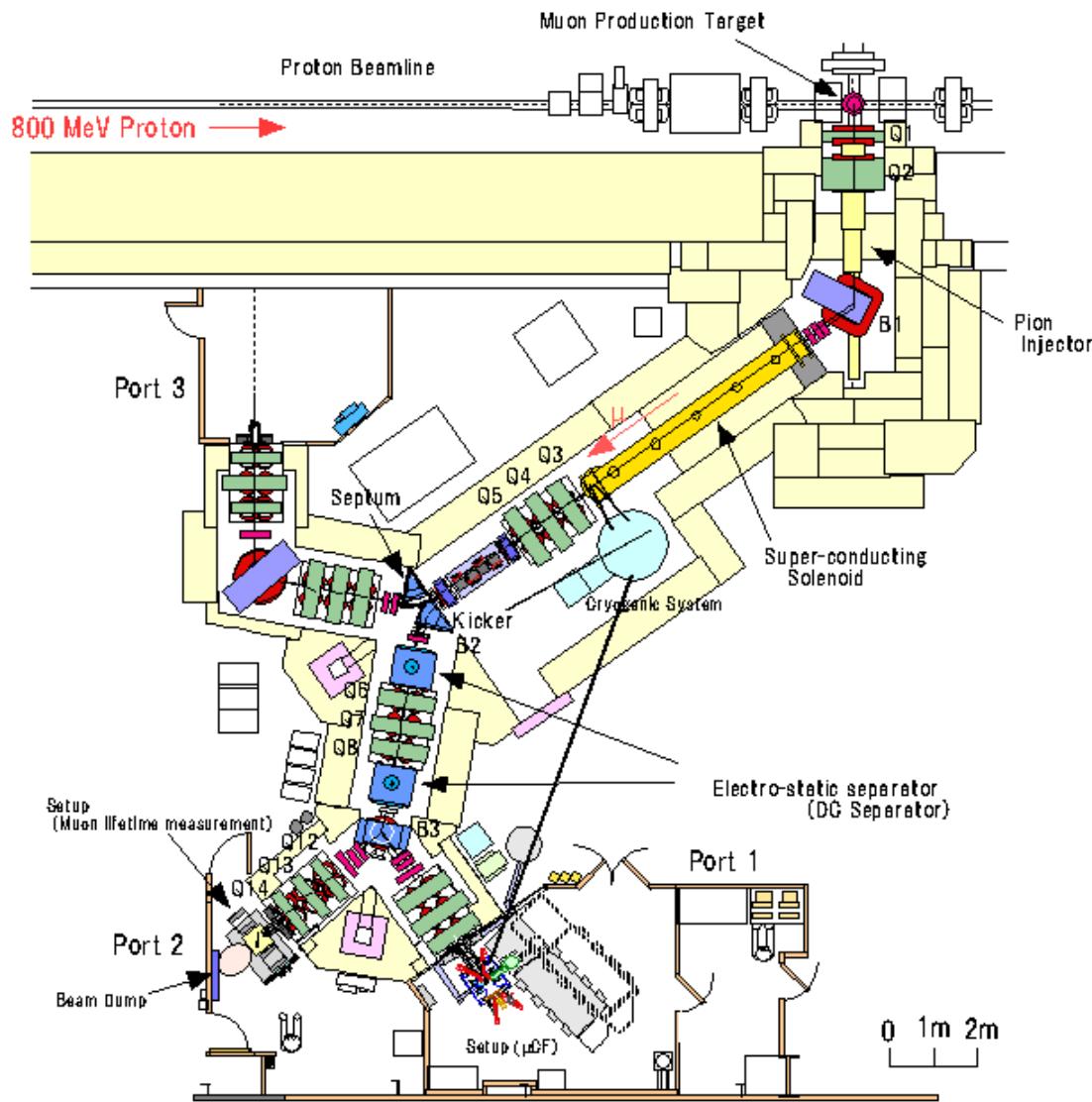
## Systematic error (Preliminary)

### ■ systematic source (main)

source	Error
Residual distortion	18.8 ppm
Data rejection	<1ppm
Correction (dead-time ambiguity)	<1.24 ppm
Correction (Positron hit rate ambiguity)	< 1.99 ppm
Clock	<1 ppm
Spin Polarization	0.1 ppm (@3500 nsec)
Total	< 19ppm

Analysis of the systematic source is in progress

# RIKEN-RAL muon facility in UK



RIKEN-RAL Muon Facility

## ■ Proton synchrotron ISIS (Rutherford Appleton Lab.)

- Proton synchrotron
- 800 MeV 200  $\mu$ A 50 Hz
- Double pulse structure ( $\sim 325$  nsec)

## ■ RIKEN-RAL Muon beam

- surface muon beam
- polarization  $\sim 100\%$
- Momentum  $\sim 27$  MeV/c
- $N \sim 10^6$  counts /sec